The Time Machine by Expanded Spectrum Systems

Most of us find the concept of time travel to be very intriguing. However, even our most advanced technology has not yet made physical time travel possible. Advances are constantly being made that at least allow the past to be preserved. Amateur radio operators function in a virtual world, and deal with information in a form that is readily preserved. Recording devices and media such as the audio cassette, the video cassette, the CD-ROM, the PC hard drive, the mini-disc, and the solid state MP3 recorder provide powerful options for preserving amateur radio communications for near term or long term needs and interests. To date, most recordings of amateur radio frequencies have been channelized, where the audio output of a receiver is connected to a recording device. However, most amateur HF operation is anything but channelized. The Time Machine presented here offers a means of recording a block of HF spectrum, which may then be played back into the RF input of any HF receiver at a later time. The interactive effect of tuning around and hearing a band full of signals from the past makes the recording seem so lifelike that one must constantly resist the temptation to answer a CQ or to break into a DX pileup. Not only does the Time Machine allow RF spectrum to be recorded on a common audio recording device, but through a novel design approach, it captures a block of spectrum that is two times the audio bandwidth of the recorder.

Wide Bandwidth RF Recording
The recording half of the Time Machine is a special purpose HF I-Q demodulator very similar in concept to the Binaural I-Q Receiver described by Rick Campbell. [1] The incoming RF spectrum is directly down converted to baseband Incident and Quadrature outputs, which are connected to the left and right channels of the recording device. The playback half of the Time Machine is special purpose I-Q modulator, which re-modulates the left and right audio channels onto a suppressed RF carrier. At first glance, the Time Machine appears to defy the laws of physics by capturing a block of RF spectrum that is two times the audio bandwidth of the recorder. Both channels of the stereo recording device are fully utilized in the I-Q recording and playback scheme, where signals below the recording local oscillator (LO) frequency are captured as "lower sideband (LSB)" signals, and those above the LO frequency are captured as "upper sideband (USB)" signals. For example, assuming an audio recording bandwidth of 40 kHz, signals would be recorded from 40 kHz below the LO frequency to 40 kHz above the LO frequency, meaning that an 80 kHz segment of the band can be recorded and played back later. A way to visualize what is happening is to think of the nature of an RF signal on a particular frequency. The complex representation of any single frequency signal is a circle. Think of I and Q graphically as X and Y. Signals below the LO frequency are recorded as counter clockwise rotating circles, and those above the LO frequency are recorded as clockwise rotating circles. The analogy can easily be observed by connecting the I and Q outputs of the Time Machine to the X and Y inputs of an oscilloscope, and slowly tuning a signal generator through zero beat with the Time Machine's LO. The farther the signal gets from zero beat, the faster the dot spins in a circle. Imagine a band full of signals as the voltage addition of thousands of circles, with half of them spinning counter clockwise and half spinning clockwise. Do not be confused by the fact that signals below the LO frequency are recorded as LSB and those above are recorded as USB. The captured signals anywhere in the recorded spectrum may be of any modulation type: LSB, USB, CW, AM, PSK, etc. The fact that the signals may be spectrally inverted during recording and reconstructed during playback is irrelevant.

The Recording Section
The Time Machine is constructed on two printed circuit boards: a main board and a plug-in band pass filter (FL1) board. This way, multiple band pass filter (BPF) boards may be constructed so that the user is not limited to operation on a single band. The recording section of the Time Machine routes the antenna input signal through the plug-in BPF board to limit the total spectrum of energy reaching the front end RF preamplifier and the mixers to prevent overload from out of band signals. To accommodate the wide range of signal levels possible with multiple bands and antenna configurations, there is a switch selectable 20 dB attenuator between the RF preamplifier and the mixer inputs. For optimum RF performance and to avoid wasting front panel space, the switch is mounted to the PC board as close as possible to the attenuator circuit. The switch should be set for optimum performance before installing the top cover on the enclosure. The RF preamplifier (AR1) is a Sirenza Microdevices SNA-386 chosen for its 50 ohm input and output impedance, wide dynamic range, and low cost. The Mini-Circuits TUF1 high level double balanced mixers (U1, U2) were chosen for their high performance and low cost. A prototype 40 meter Time Machine was constructed using NE602 mixers, but cross modulation from high power AM shortwave broadcast stations and overload from a local ham resulted in unacceptable recordings. Gain ahead of the mixers is minimized to maximize dynamic range. Therefore, to preserve the noise figure of the receive section, the mixers are followed by exceptionally low noise operational amplifiers (U3, U4). Discrete transistor amplifiers may have resulted in lower cost, but the precise gain of the feedback amplifier configuration is important for image rejection. An extensive search for low noise, single supply operational amplifiers pointed to the Maxim MAX410 as the winner based on performance and availability.

The Playback Section
The playback section of the Time Machine is simple in comparison with the recording section, and comprises a pair of TUF1 mixers (U5, U6) driven by the quadrature LO. The recorded path received using the "early" phase of the LO gets played back using the "late" phase of the LO to avoid a spectral inversion. A balance adjustment potentiometer (R21) is provided to minimize image responses. The component values in the balance adjustment circuit were selected to make the setting less sensitive near the center of the control and more sensitive near the extremes. The adjustment will probably not be necessary unless there is excessive amplitude imbalance in the recording device. This adjustment was made part of the playback circuit so that it can be used to correct for amplitude errors when Time Machine recordings are shared over differing recording devices or the internet. An interesting note is that signals that were recorded using one LO frequency can be played back using an entirely different LO frequency. For example, signals recorded on 40 meters can just as easily be played back on 10 meters. One can also invert the spectrum by crossing the left and right cable connections to the audio playback device. For example, USB signals would then appear on the opposite side of the LO, as LSB signals.

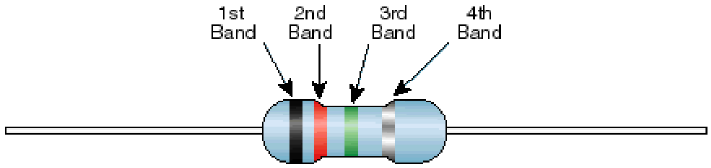
The Quadrature LO
The key to being able to accurately reconstruct the recorded RF spectrum without interference between signals above and below the LO frequency is to have an extremely accurate quadrature local oscillator. Therefore, the I and Q outputs of the LO are derived digitally. A crystal operating at the desired fundamental frequency (half frequency on 10 meters) is multiplied by a factor of 4 (factor of 8 on 10 meters) by the ICS501 (U8) clock multiplier circuit. This signal is then converted to a pair of square waves that are 90 degrees apart in phase by the 16V8 (U9) programmable logic device (PLD). Signal and LO circuit paths are kept identical between I and Q to minimize amplitude and phase errors. Optional phase trimming capacitors (C1, C2) are provided to compensate for the slight phase errors introduced by the operational amplifiers (U3, U4) to achieve a typical image rejection of better than 40 dB. If C1 and C2 are installed, they must be properly adjusted to avoid degrading the image rejection.

Constructing a Time Machine
The Time Machine was designed using a pair of printed circuit boards: the main board and the band pass filter (BPF) board. The BPF board can be constructed for any HF center frequency. Circuit values are provided for 80 meters, 40 meters, 30 meters, 20 meters, 15 meters, and 10 meters. The BPF and the LO crystal are the frequency determining elements. The filter values were optimized using ARRL Radio Designer, and could be scaled to other bands, if desired. Contact Expanded Spectrum Systems for assistance in designing custom band pass filters.

Where possible, through hole components are used to reduce the skill level required to duplicate the project. All parts, including the switches and connectors, mount directly to the printed circuit board. Assembling the Time Machine is not difficult, but a few helpful hints are in order. Use a temperature-controlled soldering iron with a small tip. Set the soldering iron between 600 and 700 degrees F. The soldering iron must have a 3-wire cord and a grounded tip to prevent damage to the active components due to electrostatic discharge (ESD). Use proper ESD techniques when handling the active devices and the assembled boards. Use only rosin core solder, of course. It is also a good idea to keep a roll of braided solder wicking wire handy in case a part has to be removed. Please note the proper orientation of the integrated circuits, diodes, and polarized capacitors. Install the surface mount devices (AR1, U8) first. Carefully orient each part, tack solder two diagonal leads, and then solder the remaining leads. Wick off any excess solder. Next, CAREFULLY install the TUF1 mixers (U1, U2, U5, U6). NOTE: The mixers must be spaced off the board to prevent the top-side PCB pads from shorting to the mixer case. Use a small strip of cardboard cut from a cereal box or a matchbook cover as a temporary spacer. Alternatively, space the board off the work surface by installing 3/8" 4-40 pan head screws and nuts in the 4 corner mounting holes, pointing up. Place the mixers on the board, invert the board and place it on the work surface. Solder the mixer leads. Do not use excess solder which might run through the plated through holes and build up under the mixer, causing a short circuit. The PLD, U9, installs in a socket, XU9. The PLD in the kit is preprogrammed. The code for the PLD is available at no cost from Expanded Spectrum Systems. Before installing potentiometer R21, set the slider to mid-scale using an ohmmeter. Next, install the remaining parts, preferably in the order indicated on the parts list. Be sure to keep the connectors, LED, and switch flush with the board so that proper alignment with the front panel is maintained. Refer to the following figures for information on reading the resistor and inductor color codes.

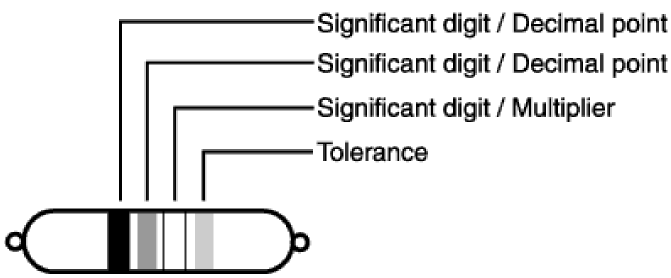
Note: Attenuator switch S2 is really a pair of 3-pin headers and a pair of DIP jumpers. The desired attenuation value is selected by plugging the jumpers onto each header from the center pin to the 0 dB pin or from the center pin to the -20 dB pin.

Standard EIA Color Code Table 4 Band: ±2%, ±5%, and ±10%



Color	1st Band (1st figure)	2nd Band (2nd figure)	3rd Band (multiplier)	4th Band (tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	±2%
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%

Chart Provided By XICON

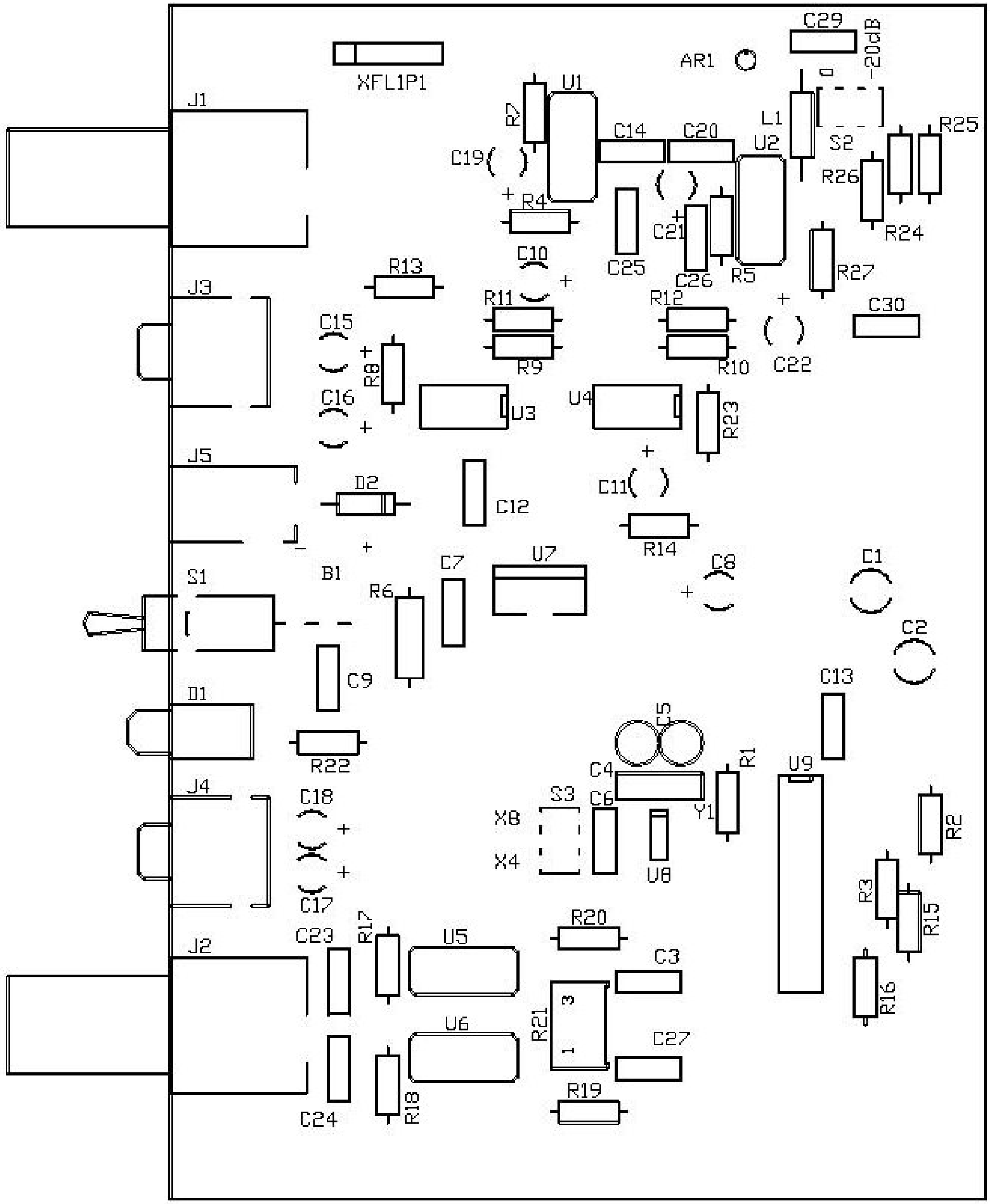


Black = 0
Brown = 1
Red = 2
Orange = 3
Yellow = 4
Green = 5

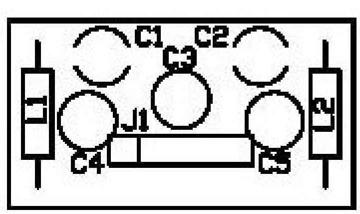
Blue = 6
Violet = 7
Gray = 8
White = 9
Gold = Decimal point
Silver = 10% tolerance

Note: The color gold represents a decimal point and will only appear in the 1st or 2nd stripe locations. When a gold stripe is present, there will be no multiplier. The inductance value will be as indicated in microHenries.

Updated: July 26, 2001



Build the band pass filter board and plug it into the main board, with the solder side facing the edge of the main board.

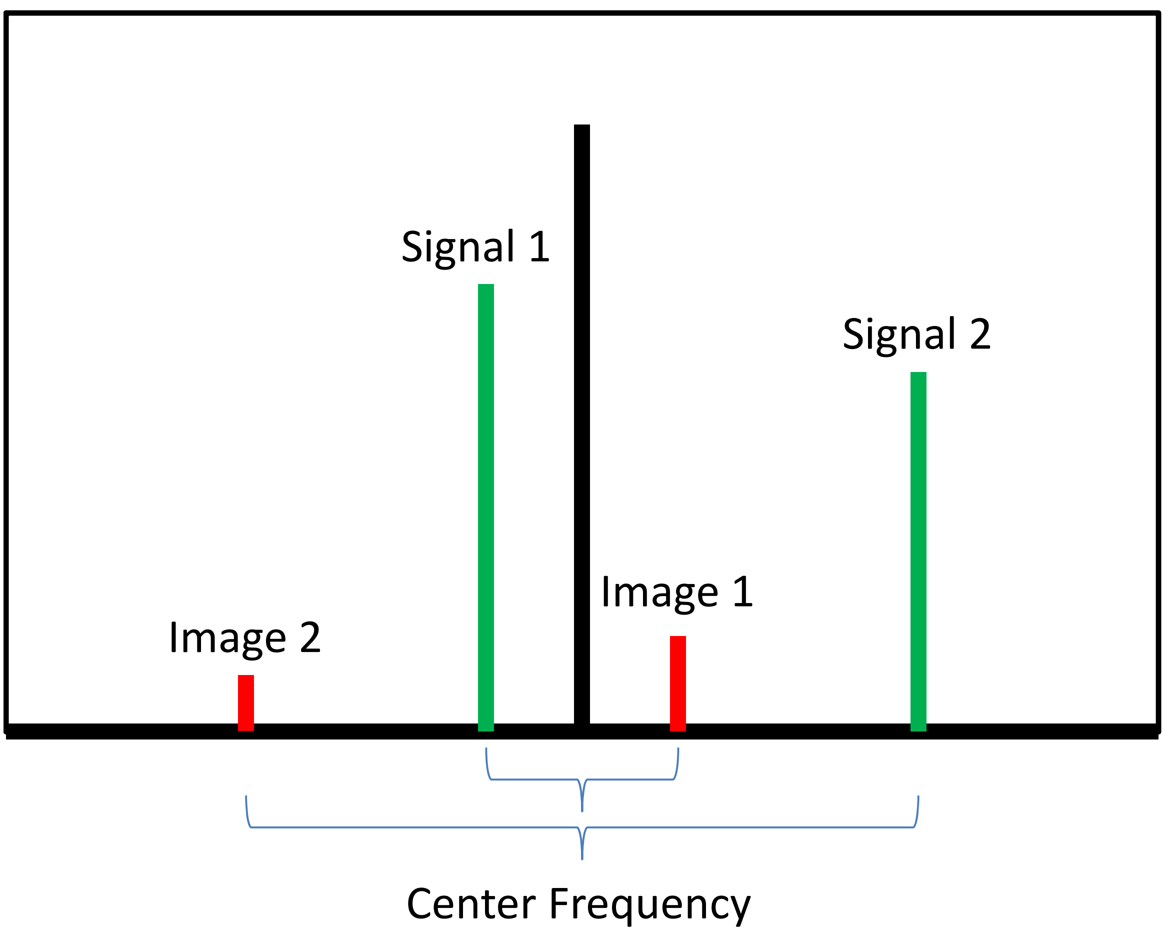


Initial Check Out
The quickest check out for the Time Machine is to perform the following steps.

1. Set S2 for 0 dB (attenuator OFF).
2. Connect an antenna to J1, the RF input.
3. Connect a shielded stereo cable from J3, the AF output, to J4, the AF input.
4. Connect a coaxial cable from J2, the RF output, to the input of an HF receiver.

   Note: If connecting to the receive input of a transceiver, be sure to disable the transmitter, or the Time Machine may be damaged!
5. Connect a DC source of 9 to 15 VDC to J5, the power input.
6. Turn on S1, the power switch.
7. Tune the receiver to the frequency of the Time Machine LO. A carrier signal should be present.
8. Tune the receiver above or below the LO and listen for a strong off the air signal. Adjust trimmer capacitors C1 and C2 on the band pass filter for maximum received signal strength.

Operating the Time Machine
Most audio recording devices provide an audio pass through path while recording. Always set the Time Machine's 20 dB attenuator for best performance while listening to signals in the audio pass-through mode. The attenuator should be set so that the observed background noise level changes slightly when the antenna is connected or removed. If image signals are observed during playback, carefully adjust balance potentiometer R21 to null out the image signal. An image will always appear symmetrically spaced from the LO frequency. For example, with an LO frequency of 7040 kHz, if a strong signal appears at 7031 kHz (9 kHz down), an image signal is possible at 7049 kHz (9 kHz up). Now is also a good time to adjust optional phase trimmer capacitors C1 and C2, if installed, for best image rejection. A spectrum analyzer and signal generator are very helpful for obtaining the optimum settings, but off-the-air signals from an antenna can also be used, as can the spectrum display available in high-end transceivers. The following figure illustrates the appearance of image signals (shown in **RED**) in relation to the LO center frequency and the desired signals (shown in **GREEN**). With the Time Machine configured as in the Initial Check Out paragraph above, adjust C1, C2, and R21 to minimize the level of the undesired image signals.

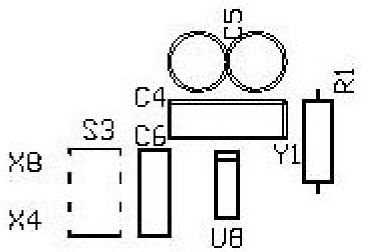


Band Settings
Plug in the appropriate BPF board (FL1) for the band of interest. Select and plug in a crystal (Y1) for the desired LO frequency.

For LO frequencies from **7.0 MHz to 21.45 MHz**, set the multiplier switch (S3) to the X4 position and select a crystal that is **at** the desired LO frequency.

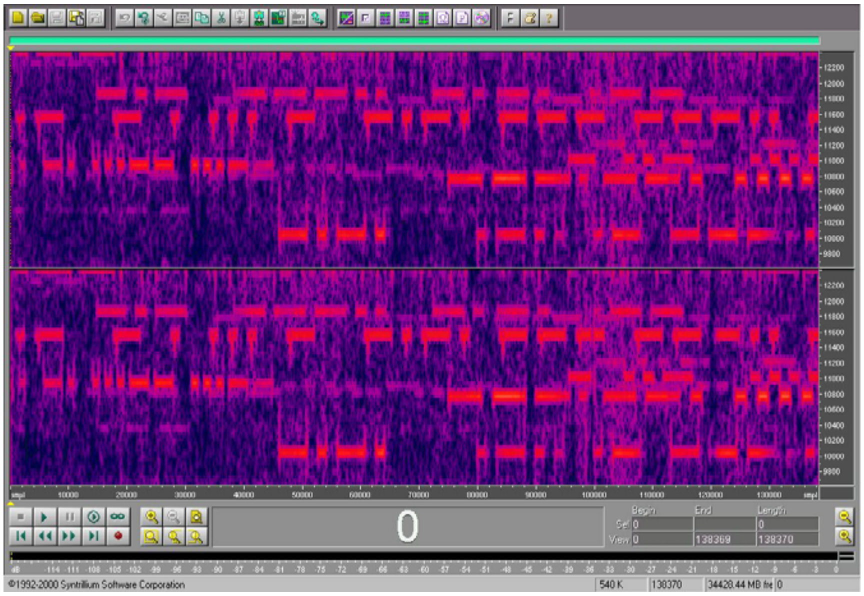
For LO frequencies **above 21.45 MHz (e.g.: 28.0 MHz to 29.7 MHz)**, set the multiplier switch (S3) to the X8 position and select a crystal that is at **one half** the desired LO frequency.

For LO frequencies from **3.5 MHz to 4.0 MHz**, carefully set the multiplier switch (S3) at the mid-point between the two normal positions, or remove the switch from the board (sets multiplier (U8) inputs to midway between +5V and ground for X2 operation) and select a crystal that is at **two times** the desired LO frequency. Refer to the schematic and to the parts lists for the main board and the BPF board for additional information.



Selecting a Recording Device
A low cost Hi-Fi VCR is the best choice when size and power are not of concern. With a VCR, approximately 80 kHz of spectrum can be captured. For portable recording and playback, it is hard to beat the portable mini-disc recorders. Mini-disc recorders should be used with the least amount of compression, and will capture about 30 kHz of spectrum. Recording directly to a PC sound card is possible, but often times there is RFI generated by the PC. For best results, record directly to a VCR or mini-disc recorder, and then transfer the recorded audio to the PC. For those with a CD-R drive, the captured WAV files can be converted to audio CD recordings that can be played back nicely using a $20 portable CD player. It is a lot of fun to play back last month's DX contest at your hamfest table using a battery operated CD player, the Time Machine, and an FT-817. The first question is usually "Where's the antenna?" Then comes "Hey, wait a minute. CQWW was last month!"

Possible Applications
The Time Machine has obvious applications for capturing and playing back contest exchanges, malicious interference episodes, special event stations, or emergency communications. Using a VCR as the recording device makes it easy to set a timer and capture what a particular band sounds like in the middle of the night. That way, one can listen and decide whether it would be worth getting out of bed to try and work that rare country needed for DXCC. Besides the obvious record and playback modes, the Time Machine has potential real time applications as well. With the internet as a broadband audio link, the Time Machine has the potential to make a networked receiver available to the world, with each subscriber able to tune around the band at will. This would be an improvement over the present channelized receivers, where each user enters a frequency of interest, thus terminating the listening efforts of the previous user. Imagine working DX using your local transmitter and a remote receiver as a way to avoid local QRM or QRN. Mating the Time Machine with a PC sound card brings many more opportunities. With the appropriate software, the Time Machine becomes a spectrum analyzer. Some testing has been done using a program called Cool Edit! as the display device for a spectrum analyzer. In one mode, the horizontal display axis is time, the vertical axis is frequency, and the intensity indicates signal strength. In this mode, it is possible to display band activity, and in the case of CW signals, to read the code directly from the screen. The resulting display is similar to the waterfall or spray patterns of the popular PSK31 programs.



A limitation when using Cool Edit! is that the LSB and USB images of the Time Machine overlap. One way around the image problem is to use an LO frequency at the band edge, but this approach cuts the amateur spectrum in half, and the band edge may not be the frequency range of interest. A much better solution would be to write software for a PC that separates the LSB and USB images using a Hilbert transform, and provides a display capability similar to Cool Edit! By using a PC sound card and some innovative software, an all-mode, software defined radio (SDR) is possible. The radio could tune anywhere in a 40 kHz band segment, with a "point and click" user interface similar to PSK31 programs. LINRAD by SM5BSZ is just such a program written for Linux (http://www.nitehawk.com/sm5bsz/index.htm). Spectravue by AE4JY is a Windows based SDR program (http://www.moetronix.com/spectravue.htm).

Contacting Expanded Spectrum Systems

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References

Rick Cambell, KK7B, "A Binaural I-Q Receiver." QST, March 1999, pages 44-48.

Parts List: Main Board

Installed (Check)	Install Order	Quantity	Item/Designation	Label-Value	Attributes	Vendor	PN
-	-	1	1	PCB	2-layer, PTH, SS, SM	Axon Circuit	
-	-	1	PS1	Power Supply, Wall Mount	CUI Stack DPD090020-P5P	Digi-Key	T402-P5P-ND
	1	1	AR1			Sirenza Microdevices	SNA-386
	2	1	U8	ICS501M			
	3	4	U1, U2, U5, U6	TUF-1	Mixer	Mini-Circuits	TUF-1
	4	1	XU9	Socket, machined	DIP20	Digi-Key	A404AE-ND
	5	2	U3, U4	MAX410CPA	DIP8	Digi-Key	MAX410CPA-ND
	6	2	C1, C2	5.5-20pF (red)	CY200D150H31	Digi-Key	SG1023-ND
	7	1	XY1	Socket, crystal	Tyco Amp 382437-1	Digi-Key	A26245-ND
	8	1	L1	22uH	(red, red, black)	Coilcraft	90-29
	9	3	R1, R14, R27	33	.25W	Digi-Key	33QBK-ND
	10	8	R2, R3, R5, R7, R11, R12, R15, R16	150	.25W	Digi-Key	150QBK-ND
	11	5	R4, R8, R13, R22, R23	1k	.25W	Digi-Key	1KQBK-ND
	12	1	R6	4.7	.5W	Digi-Key	4.7H-ND
	13	2	R9, R10	3.3k	.25W	Digi-Key	3.3KQBK-ND
	14	6	R17, R18, R19, R20, R24, R26	56	.25W	Digi-Key	56QBK-ND
	15	1	R21	2k var		Digi-Key	CT94W202-ND
	16	1	R25	270	.25W	Digi-Key	270QBK-ND
	17	2	C4, C5	33pF	CY200D100H31	Digi-Key	BC1007CT-ND
	18	15	C3, C6, C7, C9, C12, C13, C14, C20, C23, C24, C25, C26, C27, C29, C30	.1uF 50V		Digi-Key	BC1101CT-ND
	19A	2	C8, C11	330uF		Digi-Key	P10197-ND
	19B	8	C10, C15, C16, C17, C18, C19, C21, C22	100uF		Digi-Key	P5123-ND
	20	1	D2	1N4148	Axial leads	Digi-Key	1N4148DICT-ND
	21	1	D1	Green LED	PCB Mount, Chicago Miniature Lamp, 5300H5LC	Digi-Key	L20035-ND
	22	1	XFL1P1	Connector	Molex 22-28-4050	Digi-Key	WM6405-ND
	23	2	S2 Header	Connector	Amp 644456-3	Digi-Key	A19351-ND
	23	2	S2 Jumper	Jumper	Amp 881545-2	Digi-Key	A26242-ND
	23	1	S3	SPDT slide	PCB Mount, E-Switch EG 1271	Digi-Key	EG1918-ND
	24	2	J3,J4	Stereo, .125", threaded w/nut	PCB Mount, CUI Stack, SJ-3543	Digi-Key	CP-3543-ND
	25	1	J5	Power Jack, 2mm	PCB Mount, CUI Stack, PJ-102A	Digi-Key	CP-102A-ND
	26	2	J1,J2	BNC	PCB Mount, Tyco Amp, 227161-9	Digi-Key	A24495-ND
	27	1	S1	SPDT, on-on	PCB Mount, C&K, 7101MD9AV2BE	Digi-Key	CKN1059-ND
	28	1	U7	7805	TO-220	Digi-Key	NJM78M05FA-ND
	29	1	U9	16V8BQL-15	DIP20	Digi-Key	ATF16V8BQL-15PC-ND

Parts List: Band Pass Filter Board

				80m Filter			
Installed (Check)	Install Order	Quantity	Item/Designation	Label-Value	Attributes	Vendor	PN
-	-	1	1	PCB	2-layer, PTH, SS, SM	Axon Circuit	
	1	2	C1, C2	15-50pF (orange)	CY200D150H31	Digi-Key	SG1026-ND
	2	1	C3	820pF	CY200D100H31	Digi-Key	BC1024CT-ND
	3	2	C4, C5	68pF	CY200D100H31	Digi-Key	BC1011CT-ND
	4	1	P1	Connector	Molex 22-15-2056	Digi-Key	WM3003-ND
	5	2	L1, L2	22uH		Coilcraft	90-29

				40m Filter			
Installed (Check)	**Install Order**	**Quantity**	**Item/Designation**	**Label-Value**	**Attributes**	**Vendor**	**PN**
-	-	1	1	PCB	2-layer, PTH, SS, SM	Axon Circuit	
	1	2	C1, C2	15-50pF (orange)	CY200D150H31	Digi-Key	SG1026-ND
	2	1	C3	390pF	CY200D100H31	Digi-Key	BC1020CT-ND
-	-	-	C4, C5	N/A	CY200D100H31	N/A	N/A
	3	1	P1	Connector	Molex 22-15-2056	Digi-Key	WM3003-ND
	4	2	L1, L2	15uH		Coilcraft	90-27

				30m Filter			
Installed (Check)	**Install Order**	**Quantity**	**Item/Designation**	**Label-Value**	**Attributes**	**Vendor**	**PN**
-	-	1	1	PCB	2-layer, PTH, SS, SM	Axon Circuit	
	1	2	C1, C2	7.5-30pF (green)	CY200D150H31	Digi-Key	SG1024-ND
	2	1	C3	270pF	CY200D100H31	Digi-Key	BC1018CT-ND
-	-	-	C4, C5	N/A	CY200D100H31	N/A	N/A
	3	1	P1	Connector	Molex 22-15-2056	Digi-Key	WM3003-ND
	4	2	L1, L2	15uH		Coilcraft	90-27

				20m Filter			
Installed (Check)	**Install Order**	**Quantity**	**Item/Designation**	**Label-Value**	**Attributes**	**Vendor**	**PN**
-	-	1	1	PCB	2-layer, PTH, SS, SM	Axon Circuit	
	1	2	C1, C2	7.5-30pF (green)	CY200D150H31	Digi-Key	SG1024-ND
	2	1	C3	220pF	CY200D100H31	Digi-Key	BC1017CT-ND
-	-	-	C4, C5	N/A	CY200D100H31	N/A	N/A
	3	1	P1	Connector	Molex 22-15-2056	Digi-Key	WM3003-ND
	4	2	L1, L2	6.8uH		Coilcraft	90-23

				15m Filter			
Installed (Check)	**Install Order**	**Quantity**	**Item/Designation**	**Label-Value**	**Attributes**	**Vendor**	**PN**
-	-	1	1	PCB	2-layer, PTH, SS, SM	Axon Circuit	
	1	2	C1, C2	5.5-20pF (red)	CY200D150H31	Digi-Key	SG1023-ND
	2	1	C3	150pF	CY200D100H31	Digi-Key	BC1015CT-ND
-	-	-	C4, C5	N/A	CY200D100H31	N/A	N/A
	3	1	P1	Connector	Molex 22-15-2056	Digi-Key	WM3003-ND
	4	2	L1, L2	4.7uH		Coilcraft	90-21

				10m Filter			
Installed (Check)	**Install Order**	**Quantity**	**Item/Designation**	**Label-Value**	**Attributes**	**Vendor**	**PN**
-	-	1	1	PCB	2-layer, PTH, SS, SM	Axon Circuit	
	1	2	C1, C2	5.5-20pF (red)	CY200D150H31	Digi-Key	SG1023-ND
	2	1	C3	100pF	CY200D100H31	Digi-Key	BC1013CT-ND
-	-	-	C4, C5	N/A	CY200D100H31	N/A	N/A
	3	1	P1	Connector	Molex 22-15-2056	Digi-Key	WM3003-ND
	4	2	L1, L2	4.7uH		Coilcraft	90-21